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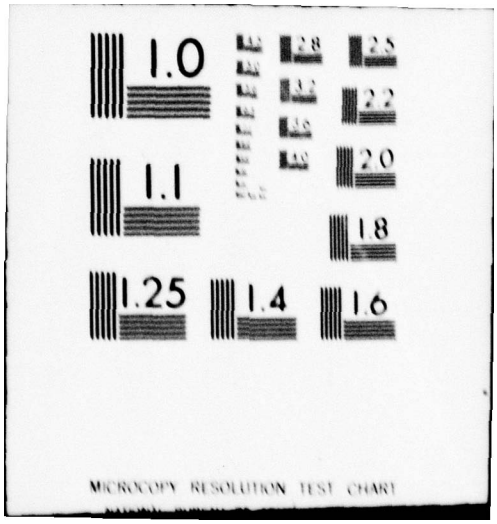
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BATTLEFIELD OBSTACLES--AN APPRAISAL OF THE STATE OF THE ART IN MEASURING OBSTACLE EFFECTIVENESS

Prepared by

Engineer Studies Group
Office, Chief of Engineers
Department of the Army

September 1976

78 10 10 000

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)

(6) Battlefield Obstacles--An Appraisal of the State of the Art in Measuring Obstacle Effectiveness,

5. TYPE OF REPORT & PERIOD COVERED

(9) Final Repts

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)

(10) Gerald E. Cooper

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Office, Chief of Engineers
Engineer Studies Group
6500 Brookes Lane, Washington, D. C. 20315

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS

Engineer Studies Group
6500 Brookes Lane
Washington, D. C. 20315

(11) Sept[illegible]76

12. REPORT DATE

13. NUMBER OF PAGES

71

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

N/A

(12) 72p.

15. SECURITY CLASS. (of this report)

UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution Unlimited.

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Unlimited.

18. SUPPLEMENTARY NOTES

N/A

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Battlefield Obstacles
Mobility/Countermobility
Obstacle Effectiveness
Obstacle-free Combat Analysis
Obstacle-related Combat Analysis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The US Army is concerned with the question: What do obstacles have to do with winning or losing battles? This appraisal collects many thoughts from a variety of sources about the measurement or demonstration of the effectiveness of battlefield obstacles, natural and manmade. From consideration of the historical record and a number of approaches to combat analysis, the paper notes that the measurement of obstacle effectiveness has remained primitive and produced unconvincing results. Part of the difficulty is traced to limitations in the representation and interpretation of obstacle-free combat. The paper concludes that, despite a number of identified difficulties, obstacle-related combat analysis can be made much more convincing and offers several suggestions toward that aim.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

404 744

BATTLEFIELD OBSTACLES--AN APPRAISAL OF THE STATE OF THE ART IN MEASURING OBSTACLE EFFECTIVENESS

Prepared by
Engineer Studies Group
Office, Chief of Engineers
Department of the Army

September 1976

ACKNOWLEDGMENTS

Early in 1976 the Commandant, US Army Engineer School, asked the Engineer Studies Group (ESG) to appraise the state of the art in measuring obstacle effectiveness. Also early in 1976, the Office of the Deputy Chief of Staff for Operations and Plans, Department of the Army, proposed that in FY 77 ESG conduct a study of the operational effectiveness of obstacles. ESG considered both requests as license to begin immediately to explore many sources of information. Everyone contacted expressed interest in the efforts and had useful ideas, comments, and references to offer. The widespread enthusiasm and cooperation of everyone are greatly appreciated. Staffs of the US Army Engineer School, Command and General Staff College, Combined Arms Combat Developments Activity, Mobility Equipment Research and Development Command, and Army Materiel Systems Analysis Agency all contributed. Dr. Wilbur Payne, Director, US Army TRADOC Systems Analysis Activity, was especially helpful.

Although this appraisal borrows heavily from the acknowledged and referenced sources, the views offered herein are ESG's own interpretations and may not do full justice to the sources. ESG felt it prudent to go on record at this time via published appraisal in order to give everyone an opportunity to set the record straight before getting too far into full-fledged study of the operational effectiveness of obstacles.

This report was prepared for publication by Mrs. Estelle C. Coleman under the supervision of Mrs. Doreen A. Myers. The editor was Ms. Jill M. Davis.

CONTENTS

ABSTRACT

The US Army is concerned with the question: What do obstacles have to do with winning or losing battles? This appraisal collects many thoughts from a variety of sources about the measurement or demonstration of the effectiveness of battlefield obstacles, natural and manmade. From consideration of the historical record and a number of approaches to combat analysis, the paper notes that the measurement of obstacle effectiveness has remained primitive and produced unconvincing results. Part of the difficulty is traced to limitations in the representation and interpretation of obstacle-free combat. The paper concludes that, despite a number of identified difficulties, obstacle-related combat analysis can be made much more convincing and offers several suggestions toward that aim.

SUMMARY

This paper addresses the state of the art in measuring the effectiveness of battlefield obstacles. The topic relates to the larger question: What impact do or should obstacles have on doctrine and tactics, on hardware, on organization, on individual and unit training, and on dealings with our allies? Or more pointedly, what do obstacles have to do with winning and losing battles?

In mostly general terms, the paper considers a variety of theoretical and empirical evidence about obstacles. Of necessity, the discussion extends to obstacle-free warfare even though few battles have ever been fought devoid of natural or manmade obstacles of some sort. The methods and results of obstacle-free combat analysis are found to provide an incomplete starting point for obstacle analysis. Nevertheless, the obstacle-free evidence seems sufficient to focus more attention on the tactical than strategic aspects of obstacles. Partly because obstacle-free analysis is so limited, measuring obstacle effectiveness is considered still only a primitive art. Both its theoretical and empirical grounds are wanting.

Possible qualitative effects of obstacles are cited from several sources. Many of these fall in a general category sometimes described as "conditioning the enemy." But, apart from direct kills, the effects usually have not been expressed in terms of the assigned tasks and missions of a force as a whole. Common sense suggests that such relations must exist. In the meantime, the usual measures seem less like MOE (measures of effectiveness) and more like MOIE (measures of incidental effects). The notion of "weapon enhancement" is presented as an example of the difficulty in defining seemingly obvious terms. In time, much can be done to reduce the weaknesses in describing and measuring obstacle effectiveness. However, some difficulties always will remain.

Some suggestions are offered for generalizing the framework of combat analysis. Although the framework includes more obstacle-related battlefield conditions and events, not all the probabilities of the events are determinable. This paper speculates a little on the relationship of obstacles to increases and decreases in battlefield uncertainties. Trials such as planned for FASCAM (family of scatterable mines) are regarded as extremely important though not conclusive enough to answer all the questions that have been raised. Apart from the time and expense of trials, there is the added difficulty that some of the

quantities that should be measured have not yet been identified. Close observation of freer form exercises and training (to the extent that safety permits) may give needed stimuli to theory, which in turn may lead to some new controlled trials.

The art and science of obstacles already include a wide range of devices and techniques--some old, some new, some hardware intensive and expensive, some involving very little hardware commitment, some requiring much time and manpower on the battlefield, some requiring very little time or effort. Relative to some other very expensive weapons requiring exceptional skills, obstacles may offer potentially high payoff for short-term, low investment. If so, increasing the effort devoted to obstacles would be justified. If not, current and planned obstacle effort should be redirected to more useful battlefield purposes.

Obstacles, as do many other topics, cut across the Army's usual functional lines. The general obstacle question is a combined arms problem of subtlety and difficulty. Given the question's importance and recognizing that there is little chance of quick, complete solution, the Army should give obstacle-related combat a high priority for short- and long-term, best-effort analysis. The paper closes with some proposals for obstacle-related research and study.

BATTLEFIELD OBSTACLES--AN APPRAISAL OF THE STATE OF THE ART IN MEASURING OBSTACLE EFFECTIVENESS

I. INTRODUCTION

1. Purpose. This paper is intended to provide a perspective from which the US Army can begin improving its practices concerning obstacles and, thereby, improving its ability to win battles.

2. Scope.

a. Warning. This appraisal does not solve the problems of battlefield obstacles. Instead, it collects many ideas about obstacles and their interactions with other weapons and men, poses several questions, judges the extent to which those questions have been or can be answered, and finally offers some suggestions for tackling the unsolved problems. Webster states that to appraise is "to judge and analyze the worth, significance or status of; esp: to give a definitive expert judgment on the merit, rank, or importance of." This appraisal of obstacle effectiveness measurement tends much more to a judgmental than analytic approach.

b. Sources. No source of information has been deliberately disregarded. However, it was not practical to give all sources their due. What are probably representative sources have been consulted, in print and in person. Annex A lists the principal sources. For better or worse, experience was a major ingredient, a source whose scope is necessarily limited and largely indescribable.

c. Products. The output of this appraisal is a set of judgments and observations (often in the form of questions) about matters related to measuring obstacle effectiveness. It also includes some suggestions for improving but hardly perfecting the state of the art.

d. Definition. The image of "obstacle" should not be limited by any preconception. Here, obstacles include both natural and manmade features. The manmade features may be produced in peacetime or wartime. Natural obstacles include woods, steep slopes, and bodies of water and other surfaces with poor load-bearing properties. Manmade obstacles include minefields, ditches, road craters, demolished bridges and tunnels, abatis, tank traps, canals, barbed wire and other entanglers, traction reducers, conflagrations, fallen towers or buildings or power lines, towns and villages, planted woods and hedgerows, and artificial lakes. Most obstacles have no special significance as things in themselves; their real significance is in relation to the assigned tasks and missions of a total force. Given the tasks and missions of most forces usually thought to be involved in armor/antiarmor operations, consideration of obstacles necessarily involves similar operations.

e. Exclusion. Armor operations in general have already received a great deal of attention. This paper is not intended to repeat points recently made, for example, in the "Trainor Report"[1/] or as part of the

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1/ DA, HQ, ODCSRDA, Improving the Army's Anti-tank Capability Study (U). (SECRET).

Antiarmor Systems Program Review (ASPR).[2] Nor is it necessary to cover the details already recorded in the Weapons Systems Evaluation Group's (WSEG) published report on the Middle East War of October 1973.[3] To be sure, these and other sources have influenced the comments offered in this paper; the comments here are more in the nature of overall impressions from these sources than dissections of details.

f. Audience. This paper is not addressed directly to military scientists. The principal audience is intended to be those who make military decisions based in part on the theoretical and empirical evidence offered by analysts of many types; e.g., military historians, operations analysts, and systems analysts. The subject of the paper is the state of evidence regarding the effectiveness of battlefield obstacles, but the discussion extends to other evidence about combat. The paper does not attempt to confirm or refute any particular contention about obstacles in particular or combat in general. The application of a little healthy skepticism leads to several queries about just what is actually known. The list is sobering. It should be of interest to the decisionmakers. Less directly and without suggesting that all doubts

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2/ DA, Combined Arms Combat Developments Activity, Antiarmor Systems Program Review; Trainor Report Fact Sheets, Presentation Abstracts, and Summary (U). (SECRET).

3/ DOD, WSEG, Preliminary Assessment of the Effectiveness of Weapon Systems Used by Opposing Forces in the October 1973 Middle East War (U). (SECRET).

are removable, the list does challenge military scientists to upgrade and more clearly delimit the evidence they provide from all their sources.

3. Background.

a. Conventional wisdom has never disputed that natural and manmade obstacles have some deserved place in the past, present, and future of warfare. But, the current doubt is about just how much time, space, and effort to devote to obstacles in peace and war. Those who never thought much about obstacles have become interested in them because many of the other battlefield options have become so expensive and require special skills. Many people now wonder whether obstacles in one or more of their many forms may offer much-needed economies. The engineers, with primary responsibilities in obstacle and counterobstacle operations, have always been concerned with obstacles. Obstacles impose just one of many competing demands for peacetime and wartime engineer resources. The engineers recognize that obstacles have related implications in hardware requirements, in organization, and in individual and unit training. The implications extend to other combat arms and logistics and back again. The hardware developers already have some new ideas in obstacles. Not only do they suggest some ways to do old things with less resources, they also propose some ways to do different things using different kinds and amounts of resources--not necessarily inexpensive or classically associated with the engineers.

b. Extending far beyond obstacle matters, the Army is in the process of developing and implementing major doctrinal and tactical changes. Because some of the notions about time, space, and effort in warfare are changing, the specific nature of obstacles needs to be reconsidered. For many years, the battlefield effects of obstacles were presented mainly in terms of directly produced casualties and delayed enemy movement. Terms such as "enhancement" were often mentioned but not quantified. In March 1975, the Engineer Studies Group (ESG) published a short paper[4/] suggesting the extent to which an obstacle may enhance the effects of direct fire weapons. But, one may also ponder the extent to which direct (and indirect) fire weapons enhance obstacles. Given a particular battlefield result, determining the enhancer and enhancee is not trivial. Because of the critical part that "obstacle effectiveness" should play in the hard decisions about obstacles in particular and combat engineering in general, the US Army Engineer School (USAES) asked ESG to appraise the state of the art in measuring obstacle effectiveness. At about the same time, the Office, Deputy Chief of Staff for Operations and Plans (ODCSOPS) proposed that ESG conduct research in FY 77 to "quantify the contribution of obstacles and barriers to total force effectiveness." This paper's appraisal of the state of the art is a necessary preliminary to the DCSOPS-sponsored effort.

4/ DA, OCE, ESG, Measuring Obstacle Effectiveness--A Fresh Perspective. (UNCLASSIFIED).

II. OBSTACLE-FREE COMBAT ANALYSIS

4. Some "Obstacle-free" Considerations.

a. A request to appraise often implies suspicion that all is not well. In any case, there is a requirement for a standard against which to make judgments. Therefore, it seems reasonable to begin by appraising a situation which many say has an advanced state of the art--obstacle-free combat. A quick look at obstacle-free combat has several advantages beyond simple warmup. It reminds us that the analysis of obstacle-free combat has skeletons in its closets. It sets the stage for noting that many of the difficulties of obstacle evaluation have their sources in obstacle-free analyses. The purpose is not to spread blame but to prepare for the inevitable conclusion that all arms are involved and must contribute to solving the obstacle problem.

b. Purely "obstacle-free" combat is a rarity. All real land battles are fought on real ground. Whether that ground is natural or modified by man, it is likely to vary in one or more ways. To the extent that some of the ground is more trafficable, there are almost always at least some obstacle-like effects present. Even the so-called "unobstructed" movement rates applied in some combat analyses probably include some effects of natural obstacles. Though "obstacle-free" may be an unrealizable condition, it remains a useful abstraction.

c. Analyses of completely or nearly obstacle-free combat have often been applied in making decisions for or against other weapon systems.

The reasons for an obstacle-free approach and some of the consequences are rarely discussed.

(1) Analysts and their customers almost unanimously regard "conservatism" as a desireable attribute of analysis. Unfortunately conservatism is not always easy to define or understand. One popular "conservative" approach to proving a weapon system's worth is to show that it can almost "take care of itself," that it can terrorize the enemy and still survive without requiring the total support available within its parent force. If it can be shown that weapon-x can destroy enemy tanks without the additional benefit of close air support, indirect fires, obstacles, and the like, the case for weapon-x is strengthened. (Whether the cases for close air support, indirect fires, and obstacles are weakened is often overlooked.)

(2) Obstacle-free analysis is easier than obstacle-related analysis. If one makes his case for other systems without having to conduct the more difficult obstacle-related study, he and everyone else tends to forget about obstacles. (That he may be buying unnecessarily expensive kinds or quantities of other weapons may be deliberately or accidently overlooked.)

(3) In the meantime almost everyone (except engineers) has forgotten about obstacles, and no one (including engineers) has learned how to represent them or measure their effectiveness.

d. One working hypothesis that every obstacle analyst should consider is: If not now then in the very near future NATO direct and indirect fire weaponry will be of such quantity and quality that all natural and manmade obstacles will become unnecessary in both tactical and strategic senses. Consideration of this hypothesis has the advantage that it does not depend on our ability to describe and evaluate obstacles. In particular, we can ask what theoretical and empirical evidence is there of US obstacle-free superiority. What do weapon characteristics, recent history, and model/simulation/gaming results tell us about near future obstacle-free warfare?

(1) At close range, individual US weapons are qualitatively superior to their Soviet counterparts only in some very special circumstances.

(2) In Europe, the US would face a numerically superior force. Relative strength would vary greatly from place to place. Facing a major attack, a company team with 12 to 18 armor/antiarmor weapons typically might defend against 60 to 100 counterpart weapons. However, the typical 4:1 to 6:1 force ratios can be exceeded locally as the result of planning, accident, attrition, or confusion. Ratios as high as 15:1 are not unexpected.

(3) At close range, the typical attacker ratios would usually be sufficient to overcome the defender despite the frequently cited advantages of a well-chosen, well-prepared defensive position.

(4) At greater ranges, some individual US weapons do have some qualitative superiority. Most of that superiority, however, lies in slow-firing weapons and slow-flying projectiles.

(5) Given likely weapon mixes, some analysts give the defender the consistent edge at 3:1 or less in an obstacle-free environment. Whenever the ratio is 6:1, they generally consider the advantage to have swung very strongly in favor of the attacker. The attacker suffers initially at the greater ranges but brings enough surviving firepower to closer range to win the complete battle.

e. Thus, the first working hypothesis about obstacle-free combat goes down in defeat. Agreement about that seems widespread though not unanimous. Beyond that there is much dispute about how to achieve defensive success in detail and in total--about how to so bloody the attacker's nose as to avoid the jaws of defeat. The standard suggestions fall in three categories.

(1) Increase (proliferate) the number of defender weapons with good longer range characteristics.

(2) Instead of fighting one complete battle to self-extinction, fight a succession of much shorter encounters--disengaging each time before the attacker gains an advantage--by recovering from surprise and/or by closing to shorter ranges.

(3) Prolong the combat time at defensively favorable ranges in each engagement. Hold part or all of the attacker at a range or ranges chosen by the defender.

f. The second and third suggestions have much in common in the sense that more of the total time is to be fought under conditions favored by the defender. Suggestion e(2) achieves a larger favorable fraction of time as a summation over many shorter battles. Suggestion e(3) achieves the fraction within a single battle.

g. The first suggestion, to increase the defender's firepower by proliferating current weapons, leads some people to ask...

(1) How reliable are the "official" individual weapon characteristics? Are they heavily based on one-on-one dual considerations? Some combat models do not allow weapons to fire beyond their so-called "maximum effective ranges." Yet, there is some evidence to suggest that practical maximum effective range depends on the number of weapons on both sides and on attacker formation and tactics. It is not unreasonable to suppose that the practical maximum effective range of 10 attacking tanks differs from that of just two tanks.

(2) Are there enough skilled gunners (in being or developable) to exploit an increase in weapons? How much improvement can be achieved (at what cost?) by selecting better gunners for existing weapons? There is no simple answer. The question is complicated because different weapons require different skills. Many older weapons draw much

of their strength from repetitive fire. Some newer weapons are less dependent on repetitive fire techniques.

(3) What do proliferated long-range systems do when the attacker manages to close to very short range? Every engagement includes an element of uncertainty. We can be certain that somewhere, sometime the attacker is going to close. The weapons that fire projectiles that do not arm until they have passed nearby attackers may be at a double disadvantage.

h. The suggestion to fight many short battles raises some other questions.

(1) Is Germany east of the Rhine deep enough to fight a complete campaign of quickie engagements and disengagements yielding some ground each time?

(2) Are the defender's powers of command and control and repositioning sufficient?

(3) Will much of the defense have to stand and fight sooner or later?

i. The third approach may be expressed as a seemingly facetious suggestion to put multilingual stop signs at the ranges favorable to the defender. The suggestion seems less facetious when it is realized that a large road crater is understandable in any language. It may even be understandable in total darkness. The skeptics ask some pointed questions.

(1) How can encountering a road crater ever be as decisive as getting shot and killed? Death, too, speaks a universal language.

(2) What already outnumbered force will have enough time and energy to create obstacles? And if the creation of obstacles has a multihour or multiday leadtime, how does the defender know where to put them? How can such obstacles escape detection long enough and well enough to achieve any tactical surprise?

(3) And, again, just how reliable are the "official" individual weapon characteristics that credit any of our weapons with a sustainable range-dependent edge? It is not much safer to depend on a first-round advantage with its element of surprise than to depend on supposed Nth-round advantages in the face of returned, suppressing fire?

(4) How can anyone be sure that unrestricted defender mobility for counterattacking is not more valuable than restricting the attacker's mobility?

(5) Should different defender weapons be positioned at roughly the same or different ranges? Whichever the choice, can defender weapons be positioned so their relation to obstacle and attacker is independent of the direction of attacker approach?

(6) Is there a significant risk that the stopped attacker can more easily detect defenders, more rapidly serve his weapons, and more accurately fire?

j. The "stop sign" suggestion leads to an obvious generalization, the "stoplight." Letting a few attackers through at a time may let the defense divide and conquer the attack in detail. And of course, a system of valve-like devices across a multilane attack directly generalizes the one-lane, one-stoplight notion.

k. The above suggestions are not mutually exclusive. Acceptance of one need not imply exclusion of the others.

l. If the working hypothesis had been correct, everyone could have relaxed in the knowledge that all tactical battles would be won and all those tactical wins would win the war. Instead, we found several ways in which tactical battles may be lost in the obstacle-free environment. Hence, we have to consider combinations of tactical wins and losses, in particular what combinations of small-scale wins and losses distributed in space and time correspond to forward edge of the battle area (FEBA) movement and to larger scale wins and losses. Modelers of large-scale combat are quick to point out that they do not represent penetrations and envelopment. Modelers of small-scale combat seem more confident in that they have represented more of the conceivable events and outcomes of first battle (usually with the glaring exception of close combat) and have developed fairly reasonable estimates of the likelihoods of different events and outcomes....at the tactical level. But, even they are not very confident about the performance of the same unit in its later battles at the same or different location against the

same or different attackers. In its candid moments, the analytic community admits that it is not really confident about combining small actions across a broad front and over extended time. From the theoretical point of view, we become very concerned if we consider defense to be chain-like and governed by its weakest and/or defeated links. Individual link standards must be very high if overall success requires each element to win and not just achieve a simple majority. We include the problem of building a representation of large-scale combat from small-scale ingredients within "combat combinatorial dynamics" or "combatorics" for short. Although we find much that is questionable in the representation of small-scale obstacle-free combat, it is "combatorics" that worries us the most. Indeed, it is the sorry state of the art of combatorics that explains much of the difficulty in the art of measuring obstacle effectiveness.

5. Combatorics.

a. We can include a wide variety of problems within combatorics. These problems involve not just combinations of combat events but the extent to which those events are dependent.

(1) The smallest battle consists of one defender and one attacker. A larger battle consists of M defenders and N attackers. Some analysts regard the M-on-N battle as decomposable into and hence equivalent to a number of independent 1-on-1 engagements, at least initially. Other things being equal, the advocates of independence expect combat results to depend very strongly on force ratio (N/M). Other analysts

assume that there is interdependence among the engagements. Those analysts may be willing to decompose the M-on-N battle to some extent. But, if they do, they may limit the decomposition to m-on-n engagements in which there is combinatorial dependence in some sense. They would argue that battles of different sizes at the same force ratio would produce some difference in results because the ratios of the numbers of relevant combinations would differ. Hence, they would suggest that results depend not only on force ratio but also on total force. Differences in rates of fire or one-round kill probabilities may, among other effects, influence the degree of dependence.

(2) We used combatorics for considering the combination of small battles into larger scaled combat, in building macro-combat from micro-combat, possibly in the sense of considering a complete FEBA to be built from many FEBA segments. The converse process is also of interest. A given FEBA segment may be broken into smaller segments. As viewed by an attacker, the given segment may represent some whole relative to the integrity of plan. If the defender can split that whole segment battle into two smaller battles "moving" at different rates, the attacker may be disrupted or fractured in a way that would lead to its defeat in detail.

(3) Combatorics should also include events combined over time. People generally consider what happens next to depend on what happened before. Depending on how we define terms, we can consider widely different degrees of dependence with respect to time. Certainly

much of the dependence among weapons or among units is subject to delay. The flows of information and the reactions to that information are typically subject to delay.

(4) The same forces may engage at different places (necessarily at different times). The different places may have different terrain. Some terrain difference may have been manmade. Other things being equal, consider two campaigns: the first consisting of a battle at A followed by a battle at B, and the second consisting of a battle at B followed by a battle at A. In the combinatorial sense AB and BA are the same. Yet, we suspect that order may be very important; we are suggesting some permutational dependence. Indeed, we do not generally expect the results of campaigns AB and BA to be the same. The reason for introducing this notion should become clearer in the following.

(a) Let campaign AB cover entirely natural terrain.

(b) Suppose resources are available to modify the terrain in some sense (obstacles?). Represent modified site A by A' and modified site B by B'.

(c) Now consider some new campaigns: A'B, AB', and A'B'.

(5) Whereas the obstacle advocate expects all these to produce better results than the base campaign AB, we have encountered some model results in which A'B produced an inferior result. The only plausible explanation was that, by prolonging the battle at A, the

defender inadvertently allowed the attacker to apply reinforcing units to the later battle at B. The terrain at B was such that the now stronger attacker did much better overall than if he had been permitted to traverse A at normal speed.

(6) Despite this example introducing dependence on order and not just on combination, we still regard the order-dependent problem a part of combatorics. Note that a similar argument may apply if locations A and B are adjacent elements under simultaneous attack. Both AB and A'B' may be inferior to either of A'B or AB', from the defender's point of view. A'B and AB' might imply a break in the coordination of an attack, perhaps upsetting some simultaneity key to the attacker. The attacker might choose to redirect his entire attack through the unmodified sector.

b. Clearly, this discussion of combatorics is setting the stage for much that is obstacle related. In that sense, we are getting ahead of ourselves. The remaining paragraphs in this section cover topics that should be addressed before we take up the subject of obstacles directly.

6. Standard Systems Notions.

a. The quantitative representation of combat involves many of the same technical considerations as would any complicated system of entities, places, and times in which the entities change condition and interact in ways dependent on the entities themselves, their positions,

and the time. All this is often implicit in the assertion that a system is "dynamic." Much of man's intellectual history has been spent contemplating systems of many sorts; in trying to discover which things change and which do not; and in attributing causes. Combat generally involves changes in the numbers of its entities (by addition, deletion, and restoration), changes in the condition of entities, and changes in the position of entities. Consideration of specific combat requires some precision in defining these notions. Typically that consideration also involves aggregation of one or more sorts: of individuals, conditions, positions, or time. We can define "event" in any one of several ways. For example, we can consider an event simply a change of number, condition, or position--recognizing that we can define both number and position as conditions.

b. Among other things, complete, detailed representation implies that we enumerate all conditions and events. That is, we identify all the conditions that can exist and all the transitions that can occur from one condition to another. Here the word "condition" by itself should imply something purely instantaneous.

c. In considering any one representation of combat, we should ask some questions about "conditions." The most important is, "Just what conditions are represented?" Sometimes we find just two represented: life and death. Until demonstrated otherwise though, we believe that many more conditions must be represented.

(1) Kinds and degrees of skill.

(2) Degrees of physical and mental condition.

(3) Levels of supply of ammunition and POL.

(4) Mounted or dismounted.

(5) If mounted, buttoned or unbuttoned.

(6) Kinds and intensities of activities such as searching, detecting, acquiring, loading, firing, sensing, hiding, digging, breaching, attacking, withdrawing. (Here again we see how we can mix notions: if position is a condition, changing position by any means may be more a succession of conditions and events than a single condition.)

(7) Levels of daylight, visibility, intervisibility.

(8) Using or not using vision aids, navigation aids, automation.

d. Also, in considering any one representation of combat, we should ask questions about the transitions from one condition to another. Are all real transitions represented? If represented, is it done with certainty or other specified probability? Do the rules of transition depend on current condition, position, or time? Do the rules of transition depend on past conditions? Do the transitions depend on some prediction of future conditions?

e. A universal representation of combat would be nearly infinite in several respects. No one claims to have a universal model of combat, although some are threatening to become infinite. Indeed, all known

representations have been developed for limited purposes even though uses have often exceeded original purposes.

f. If doctrines are known and combatants adhere strictly to them, the number of conditions and transitions that need be represented may be greatly reduced from the universal model. Typical realistic difficulties are at least some ignorance of enemy doctrine and the very real possibility of battlefield departures from doctrine. Troops have panicked, broken, and run. Commanders and men have made innovative uses of the resources at their disposal. Heroism has occurred at unusual times and places. Not all these realities lend themselves to adequate treatment as some sort of aggregated uncertainty.

7. A Few Model/Simulation/Game Concerns.

a. The following list includes many of our concerns about representation of relatively small-scale actions.

(1) Probably too frequent assumption of daylight, sunny, and clear conditions.

(2) Underplay uncertainty.

(3) Tend to disregard intelligence.

(4) Underplay command, control, and communication.

(5) Unlikely to represent electronic warfare.

(6) Unlikely to represent close combat.

(7) Little agreement about when and how battle ends. Often assume near-annihilation is "equivalent" or "proportional" to result at real prior termination.

(8) Tend to underplay troop adaptability.

(9) As yet, no representation of military operations in built-up areas (MOBA).

(10) As yet, no convincing "continuous operations" representation.

(11) May underplay friend/foe identification problem.

(12) May underplay problem of discriminating live and disabled vehicles.

(13) May misrepresent timing and level of resources allocated at higher command levels--some indirect fire weapons, close air support (both friendly and enemy).

(14) Dependence of events-in-the-small on events-in-the-large and vice versa.

(15) Difficulty in translating simultaneous real events into a purely sequential process representation.

(16) Too much freedom to vary input independently when real counterparts almost certainly are dependent.

(17) Use of input based on wide variety of different circumstances to represent current interest.

b. The following list extends our range of concern to representations of relatively large combat actions. Some of the items overlap those in 7a above.

(1) Aggregation of diverse weapon and unit characterizations as one or a few indices, perhaps assumed linear in the different members of the aggregate and implying such concepts as that some number of rifles is exactly equivalent to a tank.

(2) Implication that a spatially distributed unit occupies a single point and moves along a single line.

(3) Importance of FEBA movement. Its aggregation from the movements of FEBA sections, the magic of FEBA-smoothing algorithms applied between periods of battle. Annex B summarizes some history of popular data.

(4) Frequent limitation of traffic across sectors and flowlines "drawn" on the battlefield.

(5) No representation of penetration and envelopment; no grand strategy in general.

(6) Letting wars "run" weeks beyond reasonable predictability.

(7) Allocation of aircraft among intra-air, interdiction, and close air support roles. Great uncertainty about attrition to and from aircraft and the impact of that attrition.

(8) May underplay importance of rapid logistic response, especially in high-attrition wars.

(9) Tendency to overestimate friendly readiness and ability to reinforce, tactically and strategically.

(10) Dependence on nonobservable, unmeasurable factors.

(11) Too much freedom to vary input independently.

c. The remaining comments apply to models/simulations/games in general regardless of "size."

(1) Frequency of incomplete, obsolete documentation.

(2) Lack of a "smallest equivalent" counterpart for demonstration and experimentation.

(3) Blurring of distinctions between logic and data.

(4) Reluctance to apply same arguments and assumptions to all combatants. In the absence of data, it is generally impossible to make unbiased assumptions.

(5) Almost all so-called validation is simply comparison with "intuition." There is no consistent mechanism other than seniority for resolving differences between results and intuition and between different intuitions.

(6) Tendency to equate value of result with level of effort.

(7) Reluctance to acknowledge counterexamples.

(8) Suggestion that small errors stay small. Fallacy 1: 1 percent input error corresponds to 1 percent output error at most. Fallacy 2: 1 percent error in input to each stage of a multistage process keeps error after N steps to 1 percent at most.

(9) Disregard of chemical and biological weapons and effects.

d. No one model/simulation/game is necessarily liable to all the above concerns and limitations although some come very close.

8. Inevitable Reference to October 1973 War.

a. The Middle East war of October 1973 is being cited as evidence of much. Of course, not everyone gives the same interpretation and not all interpretations are given identical distribution. Among the most disturbing interpretations are:

(1) Proved obsolescence of the tank.

(2) Defender's ability to blunt and contain penetrations.

(3) New limitations of close air support.

b. The Israelis were caught off guard. In the early stages they resorted to desperate measures. These measures were not outright failures; they were expensive to both Arabs and Israelis--a result somewhat contrary to expectations based on the 1967 war but not unpredictable.

c. What is the danger? US/NATO politicians (and maybe some of their military) are liable to be comforted in the knowledge that Israel, despite the surprise, blunted both Egyptian and Syrian attacks. And much of the credit may be given to "modern weapons." Certainly modern weaponry did have much to do with battle results--especially in detail. What may be overlooked by some is that general results were probably most influenced by objectives. The Arabs and Israelis did not want explosive superpower involvement directly. Both sides expected that

overruning an enemy would lead to such involvement. Neither Egypt nor Syria planned to overrun all Israel. Particularly Egypt had no plan to exploit early successes to their fullest. Syria's gains were never that great in total. When Israel finally counterattacked, its objectives also were limited. Evidently the Israeli assault toward Damascus did not have Damascus as an objective. Israeli forces stopped on the road to Damascus. The Israeli counterattack across the Suez Canal was widely heralded as a threat to Cairo. Yet, the Israeli objectives do not seem to have been metropolitan; they sought to isolate Egyptain forces and to destroy air defense positions.

d. Although the October War can tell us much about the tactical effectiveness of Soviet and NATO weapons, it cannot tell us much about strategic effectiveness that would be relative to Europe. In general, the analyst cannot construct a posteriori MOE (measure of effectiveness) from experience given different objectives. We do not, therefore, know much about effectiveness in stopping very deep penetrations because neither side tried to make very deep penetrations. The shallowness of Israel between Syria and the Mediterranean is not analogous to shallowness between East Germany and the Rhine.

e. There are other results that may cloud NATO/Soviet issues. The Israelis speak disparagingly of Arab tank gunnery. The Israelis recovered many Syrian tanks that had been abandoned. In some cases, at least one crew member had become a casualty. Crews had departed as a

result of panic, because crew members are not cross-trained, or for other reasons. The Israelis also captured Syrian tanks that were undamaged with remaining fuel and ammunition. Some captured tanks had exhausted fuel or ammunition or were out of one type (antitank) ammunition.

f. The Israelis suffered heavily on both fronts, despite the evidently lower level of professionalism among the Arabs. What remains is the awesome specter of a less professional, more numerous enemy with qualitatively equal equipment having come very close to succeeding completely. The Soviet equipment contained features (vision and navigation aids; chemical, biological, and radiological protection) that did not come into play.

g. How the Middle East experience might apply to central Europe is not clear. We might expect the Soviet command and crews to be more professional than their Arab counterparts. We also might expect some NATO command and crews to be somewhat less professional than their Israeli counterparts.

III. OBSTACLE-RELATED COMBAT ANALYSIS

9. A Hierarchy of Questions About Obstacles. Beginning with the question of most general concern, this paragraph poses a whole family of questions of decreasing generality. The object is to find some level of specificity at which it becomes possible to begin to answer the questions.

Paragraph 10 gives short comments and answers about the second half of the list of questions. The rest of this paper is about all the questions; however, the discussion falls short of providing concrete answers to the difficult questions. The ultimate question of interest but the one that cannot be answered at this time is (i.e., the seed question from which the others all grow):

a. What impact should obstacles have on doctrine and tactics, on hardware, on organization, on individual and unit training, and on negotiations with our allies in order to improve the US Army's ability to win ground battles?

The seed question immediately generates two more questions.

b. Relative to the assigned task or mission of a combat system or force, what is the effectiveness of obstacles?
c. What is the cost of obstacles?

The effectiveness question (b), for which there is as yet no obvious answer, generates two more questions.

d. What are the direct and indirect measures of obstacle effectiveness?
e. What values are assignable to the measures of obstacle effectiveness?

And these two questions force us to pause and ask the obvious, given question...

f. Just what is the state of the art for measuring obstacle effectiveness?

This sixth question (f) provides the practical focus and entry point for this appraisal. The efforts to answer f cause us to reconsider questions d and e, but they also lead to several other questions.

g. What empirical evidence is there of obstacle effectiveness? From combat history. From trials. From simulation/modeling/gaming.
h. What theoretical evidence is there of obstacle effectiveness? From "a priori analytics." From simulation/modeling/gaming.
i. What scale of time, space, and combat is appropriate for obstacle considerations?
j. How reliable is information about the nonobstacle aspects of combat? Empirical. Theoretical.
k. Does information about obstacles suggest changes in the assigned task or mission of a combat system or force? Or are task and mission fixed?
l. Can obstacles and their effects be represented by merely applying a "combat multiplier" to the regular input and/or output of existing combat simulations/models/games?

10. Some Short Answers. This paragraph gives some comments and answers keyed to the hierarchy of questions in paragraph 9.

a.-f. There are no short answers to the first six questions. Several of the questions are discussed at length in later paragraphs.

g. What empirical evidence is there of obstacle effectiveness?

The empirical evidence is mixed and incomplete. Much of the historical record is outdated. Many obstacle-related events are described at both tactical and strategic levels. However, those same events obviously depended on many factors besides obstacles. Historical incidents lack corresponding base cases. Hence, the historian usually cannot apportion the credit for results between obstacles and the other factors. Worse, many of the obstacle-related events are presented as things in themselves without clear relation to the assigned tasks and missions of a force as a whole.

(1) The usually cited evidence about the strategic uses of obstacles seem to fall into two categories.

(a) Obstacles and fortifications do appear to have swung final outcomes, but the time and effort to create those obstacles and fortifications are expected to be beyond practical consideration for Western Europe.

(b) Lesser obstacles and fortifications may have had some effects but did not swing final outcomes from defeat to victory. That is, many obstacle-related campaigns seem to have led to the same result as would obstacle-free counterparts; winners and losers would have not reversed roles. To be sure, times and casualties almost certainly would have dif ed. But, the obstacles and fortifications do

not deserve credit for anything more than accelerating or postponing the inevitable.

(2) The usually cited evidence about the tactical uses of obstacles includes cases in which the outcomes of small battles appear to have been swung from defeat to victory. But, as usual, other factors seem to have been involved. The qualitative if not the unapportionable quantitative evidence suggest much obstacle-related opportunity. And, to the extent that many battles make a war, the principally tactical uses of obstacles should have strong strategic implications.

h. What theoretical evidence is there of obstacle effectiveness?

The theoretical and empirical evidence of obstacle-free combat indicates that US forces have some additional battlefield requirements. This result provides some theoretical evidence, far short of actual proof, on behalf of obstacles. At least, evidence proves that obstacles, as well as the other alternatives discussed earlier, should be considered seriously. There clearly is a requirement for something beyond current plans and capabilities.

i. What scale of time, space, and combat is appropriate for obstacle considerations?

Given the primitive art of measuring obstacle effectiveness at all levels, it is clear that much work needs to be done throughout the range of combat (from small unit to theater). Our choice is to begin at the tactical

level in detail and perhaps later draw somewhat gross strategic implications. Seconds and minutes, meters, and a few to several dozen weapons seem to provide the appropriate initial scope and resolution. All notions of "theater barrier" shall be disregarded for the time being, perhaps forever.

j. How reliable is information about the nonobstacle aspects of combat?

The available information confirms the uncertainty of combat. The uses of that information generally underplay the uncertainty. Apart from not explicitly representing uncertainty, the typical analysis uses information originated under circumstances different from those under current consideration. The overworked "expected value" has lost almost all practical meaning.

k. Does information about obstacles suggest changes in the assigned task or mission of a combat system or force?

Even apart from obstacles, the highly competitive nature of hot and cold war suggests that tasks and missions must be reconsidered frequently if not continuously. Obstacles add to the urgency of continued consideration.

l. Can obstacles and their effect be represented by applying a "combat multiplier" to the regular input and/or output of existing combat models/simulations/games?

At the notional level, tradeoff between obstacles and other elements of combat seems real enough. However, elevating that notion to practical application as a multiplier of the input and/or output of existing combat simulations/models/games implies prior complete answer to the entire combat problem. In reality, we know so little about combat with or without obstacles that it seems impossible to compensate for combat's complexities by pre- or post-multiplication.

11. Some Obstacle-related History. Every dedicated student of armored operations reconsiders the battle of Kursk; it is often used to prove arguments, almost any argument. It is often cited as the WW II turning point on the Eastern front and as the definitive example of a defender's use of obstacles and fortifications. The Russians did a masterful job of obstructed, fortified defense in depth culminating in powerful counterattack by an overwhelming reserve force against a tired, overextended, seriously attrited German attacker. At the level of the micro-battle there is the incident of the armored German spearhead in the south being delayed when its lead tank foundered trying to cross a rain-enhanced, antitank ditch-enhanced ravine. That tank could not move forward or backward, the following tanks could not pass, and hours were lost before the Germans sought and found an alternate route. It is not as commonly noted that, in the several months prior to the German attack, the Russians expended about 720 man-years of effort per kilometer of front in laying mines, creating other obstacles, fortifying positions, and preparing fields of fire. Much of that effort consisted of purely

manual labor. Whether achieved with or without machines, the defense was not a hasty one. Despite that effort and the Russian defense of those positions, the Germans did make advances. Most of those advances, however, were very costly in time, men, and equipment. The Germans attacked a multipurpose meat grinder and failed although the full consequences appeared only many hours to months later.

12. Possible Obstacle Effects, Unquantified.

a. Measuring obstacle effectiveness remains a primitive art. Both theoretical and empirical grounds are weak; the empirical base is the weaker of the two.

b. Historians and theoreticians have compiled extensive lists of the events and effects attributable wholly or in part to obstacles. Not all the events and effects have been reduced to precisely defined and measured terms. Few of the events and effects have been expressed in terms directly related to the assigned tasks and missions of a force. Some of the events and effects are largely opportunities and are of value only to the extent that they are exploited toward accomplishing assigned tasks and missions.

c. Some obstacle-related occurrences may initially seem incidental effects. Direct measurement of what some consider only an incidental effect seems a waste of time: Why worry about an MOIE, a measure of incidental effectiveness? Indeed, much of the obstacle analysts's efforts at measuring seem devoted to quantifying MOIE. Not

only must the obstacle analyst quantify in this sense, but he must convert his MOIE into MOE, measures that relate to the assigned tasks and missions of a force. Or assuming that he is absolutely right in the first place, he must persuade others to change the assigned tasks and missions.

d. Alone or with other force elements, obstacles may have one or more of the following effects, tasks, or missions. Items in the list are not all mutually exclusive. Any good historian can find at least one real example of each of these.

(1) Destroy or disable attackers.

(2) Delay attacker, in whole or in part, away from or near battle area.

(3) Influence the likelihood, position, and width of attack.

(4) Thin or concentrate the density of attacker's force.

(5) Permit thinning or concentration of defender's force.

(6) Enhance defender's weapons.

(7) Divert attacker resources into less threatening, less productive roles.

(8) Control enemy penetration.

(9) Economize force in quiet sectors, and perhaps contribute to making sectors quiet.

(10) Distract the attackers' attention.

(11) Economize direct and indirect fire rounds.

(12) Cover defender withdrawals.

(13) Create local pileup of enemy forces.

(14) Interdict enemy reinforcement.

(15) Interdict enemy logistics.

(16) Stall or disable one or more vehicles to block others.

(17) Deny access to areas and facilities (e.g., enemy's own airfields, railroad marshalling yards, ports, storage areas).

(18) Force or encourage mounted attackers to dismount or to button down.

e. Many items in the above list may be grouped within a general category, "conditioning the enemy." The term has both physical and psychological connotations. At one extreme, it includes forcing an enemy to do something. At another extreme, it suggests subtly setting an enemy up for surprise.

f. The irreverent but fair question about any or all items in the list is, "So what?" A good answer must do several things. It must quantify in several senses. The answer should give both the probability and intensity of events and results. And, more importantly, the answer should relate such occurrences to the tasks or mission of the full force. Scrutiny of the list suggests that many of the items tend to be opportunities of value only to the extent that they are exploited. The creation of unexploitable opportunity might be a deficiency of obstacles or of some other part of the force. Some analysts point out that if all other weapon systems work to their specifications, some of the effects and

opportunities listed above become redundant, much like overkill; most think such danger negligible.

g. Some items in the above list suggest events of mainly tactical scale in both time and space and in the size of involved forces. Other items obviously imply much grander scale tending much more to strategic than tactical notions.

h. The above list does not reference the frequently quoted rule, "All obstacles must be covered by fire," because it is not really a rule at all. Covering by fire indeed often would be useful, but is not always necessary. Several of the strategic or interdictory concepts do not require or imply fire coverage, and only some tactical concepts imply covering fires. The daytime or nighttime application of artillery- or air-deliverable mines to an enemy artillery battery area is a tactical ploy of some promise without covering fire. Battery crews might find the movement of ammunition much less convenient and might suffer some discomfort in trying to redeploy rapidly.

13. Possible Obstacle Limitations, Unquantified.

a. Uncertainty is always a concern. For any of many reasons, an obstacle may fail to produce desired effects.

b. Manmade obstacles all imply some consumption of time and resources for their construction or creation. Requirements for time, manpower, materiel, and transportation depend on the obstacles and circumstances. The availabilities may be insufficient. Dedicated

systems may not have other needed capabilities. Flexible systems may always have higher priorities. It may be difficult to justify many such commitments during the heat of combat, but in peacetime, in advance of a battle, or during lulls in action, preparation of the ground rarely seems wasteful.

c. Wherever nature has not already very nearly completed an obstructing system, a great deal of effort may have to be expended before an obstacle or obstacles have any effect whatsoever. That is, effects may be liable to thresholds; a single, small crater in the middle of a large, open field may have no value.

d. Obstacles that must be executed after preparation may require protection before execution. Any such required guardforces are yet another resource chargeable to obstacles.

e. Many obstacles are only as good as the extent to which they are covered by fire.

f. Eventually an obstacle may provide a greater impediment to friendly mobility than it can ever be to the enemy.

g. Many obstacles may be overcome by countermeasures much less expensive than the effort required to create the obstacles. Such obstacles become a negligible inconvenience to the enemy who is countermeasure-equipped and trained.

h. Obstacles may simply be superfluous in either of two senses. Friendly objectives may be achievable with high assurance without

reliance on obstacles, or obstacles may only slightly postpone an inevitable enemy victory.

i. In general, no obstacle forces a unique action upon an enemy. The enemy still has so many options open that friendly forces can have gained very little. Indeed, obstacles may force an enemy to actions for which friendly forces are less well prepared.

j. The usual obstacles lack friend/foe discrimination, sensitivity to the direction of attempted passage, and reliable on/off mechanisms.

14. Obstacle Possibilities Revisited.

a. To the best of our knowledge, no single combat simulation/model/game incorporates all the listed obstacle effects, tasks, missions, and limitations. Given that some listed items are largely tactical and others tend to be primarily strategic and given that small unit-, division-, and theater-level combat are represented in different simulations/models/games, there is really no need that everything be crammed into a single grand combat model. Of course, all these representations should be complete and consistent. However, no single representation has yet incorporated all that seems relevant at its own level. In general, these seeming omissions are not due to deliberate negligence. The motives may be admirable: keep things relatively simple; do not build features in the absence of empirical data; do not build features that are largely abstract and dependent on unobservable, nonmeasurable parameters. Each of these motives is too inflexible. The real world is extremely

complicated; very simplified representations of it may be (and probably are) inadequate. In the absence of empirical data, imaginative representations may lead the way in determining the kinds of empiricial data that should be sought. Theory and practice must feed one another; at times empirical data will lead to theory, but at other times theory must lead the empirical search. Likewise, the seemingly unobservable and nonmeasurable may also have valuable roles to play in advancing our understanding--provided they are not presented as other than abstractions. The abstractions may lead to new, better measurements.

b. Notice that many of the items in the list are not directly observable or measurable and have not been given precise definitions. For example, "enhancement" can be discussed at great length to the satisfaction of many without being defined to the requirements of professional theoreticians or empiricists. If we do try to define "enhancement of defender weapons," we enccunter several problems. Imagine that an "enhancement factor" is an input to a combat model. If it is a typical input and if the model is typical, the enhancement factor will not be independent of other input factors. That is, any realistic change in the value of the enhancement input should probably be accompanied by changes in several other input factors. Much is said and written about the sensitivity of output to input. Much less is mentioned about the sensitivity of some input to other input. It is generally too much to expect the model to have been built to make all the dependent input

changes before it generates new output. In any case, input data are usually so scarce and expensive that irresistible pressures force most modelers to use the "only data in town" whether or not the complete data set is self-consistent and consistent with the specific case being modeled. We do not suggest that there are always other ways to proceed or that using inconsistent information is criminal. It is only criminal if the modeler forgets what he is doing or neglects to keep his customers informed.

c. Consider what enhancement might mean. Holding an attacker at a range favorable to the defender may enhance a defender weapon in some sense(s). An obstacle that stops the attacker at a chosen place may increase the probability of detecting the attacker, provide detection at a precisely known range, assure that attacker will not be lost from sight before the defender's round(s) arrive on target, yield higher hit probability because target is stationary, or simplify command and control among multiple defenders. (Each of these, if represented at all, is often subject to different input factors in a combat model.) One side effect may be to reduce the number of rounds the defender must fire to achieve a desired result, yet another facet of enhancement. Suppose the obstacle distracts the attacker in some sense. The attacker may be less likely to detect the defender. If the obstacle damages the attacker or stalls the attacker's engine, the attacker may have to manually operate otherwise powered equipment and weapons. The attacker may dismount. If

there are several attackers in a formation preferred by the attacker, the obstacle may force the attacker into a formation preferred by the defender. "Change in formation" may go as far as breaking the attacker into smaller sections which the defender can defeat in detail. Or, change in formation may produce a greater concentration of attackers suitable for targeting by the defender's indirect or salvo-direct fire weapons.

d. Enhancement is unlikely to be a pure effect; even "negative enhancement" is imaginable. For instance, a halted attacker might detect defenders more easily. The halted attacker could be less subject to errors in his weapon stabilization system. Automatic or manual serving of the attacker weapon might be easier and faster. The attacker's grim determination and adrenaline flow might increase. Delay may permit the attacker to close trailing elements and bring overwhelming strength upon the defender. Enhancement need not be instantaneous. An obstacle may have a delayed effect. Delayed effects may include the benefit that more rearward or reinforcing defenders can face a smaller, more confused, or more tired attacker.

e. The few examples above serve to suggest that obstacle and enhancement are hardly simple, unambiguous notions. The real battle remains subject to great uncertainties. Effects may be positive or negative, immediate or delayed, and they may in turn trigger showers of side effects. Many of the seemingly obvious effects are not easily related to assigned force tasks and missions. No known simulation/

model/game incorporates all these possibilities. If they were incorporated, no one would know what probabilities to assign to all of them or what delayed and side effects to add...in the same or related representations.

15. A Thought Experiment on Uncertainty.

a. The increase and decrease of uncertainty seems to lie near the heart of the gamesmanship of warfare. At least in concept, a variety of obstacles employed in a variety of ways seems capable of adding the uncertainties to which an enemy may be subjected. Surprise often counts heavily in battle. Simultaneously, obstacles may reduce the enemy's freedom of action among other things, tending to reduce the range of surprise that the enemy can draw upon.

b. Imagine that, without affecting what we expect the enemy to do, we are able to increase the likelihood of what is expected. As an example, consider the enemy's position with time. It seems perfectly natural to consider the enemy's instantaneous change of position, his velocity. Why not also consider the instantaneous change in the uncertainty in position? Indeed we can describe the enemy in two special dimensions: change of position with time and change of uncertainty with time. This new framework is useful for considering some of the obstacle's effects.

(1) An obstacle may have effects on both velocity and uncertainty. Indeed, part of the uneasiness about obstacles may be

equivalent to the notion that it is undesirable to have some reduction in velocity with large increase in uncertainty.

(2) Suppose we could build an obstacle with an effects dial such that we could control the mix of its velocity and uncertainty effects. We might set the dial to affect only velocity or to affect only uncertainty. Given the choice, which is it better to choose? Real obstacles probably never give us such pure options. They mix velocity and uncertainty effects. Practically speaking, we almost certainly would not keep the effects separate for long. Any exploitation of a great reduction in the uncertainty of the enemy's position would probably have a great impact on the enemy's later velocity.

(3) Similar examples involving variables other than position should also be relevant.

c. Many peacetime and wartime decisions are often analyzed in the position/velocity context. All that we are suggesting here is that there is probably an equally important "uncertainty context." The gamesmanship of war, particularly obstacles, may be as dependent on the uncertainty as on the other contexts. The usual "expected value" approaches to combat analysis assume away the uncertainty context. We include the treatment of uncertainty among the subjects of "combatorics."

16. Obstacle Location, Quickness, and Effort--and Surprise.

a. Three of the areas of interest in obstacles are:

(1) The locations in which obstacles may be created or emplaced.

(2) The time required to create or emplace obstacles.

(3) The human and equipment effort required to create or emplace obstacles.

b. Different kinds of obstacles often differ from one another in at least two of these areas of interest. For example, relative to older mines, FASCAM (family of scatterable mines) may be delivered to the same and different locations more rapidly at less wartime effort. But, in terms of obstacles in general, it is useful to regard "location," "quickness," and "efforts" as three independent attributes. It is then natural to ask, "How does effectiveness depend on location, quickness, and effort?" The answers can influence tactics, doctrine, and hardware design.

c. These areas of interest may be related in practice. Smaller required effort generally implies more quickness and some greater choice in location.

d. Together, quickness and location may surprise the enemy. The enemy may be surprised at the suddenness with which an obstacle appears, and he may also be surprised by an obstacle's location.

(1) We suppose that, despite FASCAM, surprise has not been given the attention it deserves. Indeed, in some respects the FASCAM hardware falls short of exploiting all the surprise inherent in the concept.

Everyone may be so pleased at the net location, quickness, and effort gains of FASCAM as to have lost interest in "isolating the impact of surprise."

(2) We suggest that there is much merit in conducting some sort of parametric or sensitivity analysis to first isolate and then better relate the importance of location, quickness, and effort.

(3) A conventionally emplaced minefield requires a relatively long leadtime and consumes much effort. Once emplaced, it may be detected by some means from a distance and thereby lose some or all of its surprise value. In concept, surprise may be restored by somehow perfectly disguising the minefield beforehand or by creating the minefield just in advance or on top of the enemy. It is within the range of current technology to create minefields over days or within seconds. For the sake of completeness, it is necessary to mention that surprise may also be achieved by making every location look like a real minefield whether it is or not.

e. Not too long ago obstacle-related combat implied unsurprising, undisguisable barriers to most people. Obviously, it need not and probably should not. People should get used to thinking about obstacles and surprise at the same time.

IV. CONCLUSIONS, PROSPECTS, AND PROPOSALS

17. Summary of Conclusions.

a. Measuring obstacle effectiveness has remained a primitive art still based on relatively weak theoretical and empirical grounds. The empirical foundations are the weaker of the two.

(1) Most of what obstacle analysts usually cite as obstacle effects have not yet been related to the assigned tasks and missions of a force as a whole. It seems certain that such relations must exist. In the meantime (apart from direct kills), measures of obstacle effectiveness look less like MOE (measures of effectiveness) and more like MOIE (measures of incidental effects).

(2) The most frequently cited historical examples of obstacle effectiveness are cases where a defender had months to prepare and devoted as much as 720 man-years of effort per kilometer of front to obstacle and fortification development.

b. Much of the weakness in measuring obstacle effectiveness is attributable to often-forgotten, little-discussed weaknesses in the representations of obstacle-free combat in both small- and large-scale military operations.

(1) Yet, at least qualitatively, some of the best perspectives on obstacles can be drawn from the quantitative representations of obstacle-free operations.

(2) The efforts to introduce obstacles to existing representations of combat have not included the full variety of obstacle-related combat events and conditions that well might occur with non-zero probability. Obstacles, particularly different obstacles employed in varying ways, seem capable of creating many uncertainties and hence surprises to the attacker. Whether or not an attacker intends to apply fixed or flexible doctrine, surprise is likely to induce some departures from doctrine. No one claims to have listed these exhaustively nor to have much notion of their probabilities of occurrence. Obstacles may infrequently force an enemy to take a unique course of action. In many circumstances, however, it seems that obstacles can restrict an enemy's freedom of action and condition him in ways helpful to friendly forces. At any one time, the uncertainty in the enemy's position may be reduced. Or, for any one location, the uncertainty in the enemy's time of arrival or departure may be reduced. In the sense that good intelligence reduces uncertainty, obstacles may have some intelligence-like equivalence. Although reducing uncertainty about the enemy may imply greater friendly opportunities and freedom of action, the reduction may have no value if not exploited. As each new weapon becomes available, many variations on older obstacle employment themes need to be explored. Some totally new types of employment also will be developed.

c. Obstacle-free analyses reveal some serious limitations of US weapons and forces. There are many ways in which these limitations

may be reduced. Many alleviating actions are under way, some on fairly arbitrary grounds. But, it is highly likely that (with the exception of FASCAM) most countermobility candidates have been underrated and underplayed. Much harder evidence, both theoretical and empirical, is needed before thoughtful decisions are made for or against obstacles. It is doubtful whether absolutely unambiguous evidence ever can be developed. However, obstacle evidence can be brought up to (and in some cases above) the standards generally applied in decisions on doctrine and tactics, on hardware, on organization, on individual and unit training, and on negotiations with allies.

(1) TEMAWS-like[5/] trials are necessary, though hardly sufficient, for generating empirical evidence (with the disadvantage that much must be known to design best experiment). Introducing more obstacle-related events (not simply signs and tapes) into conventional unit training can also generate valuable empirical evidence--less the advantage of carefully designed experiment.

(2) Although empirical evidence is often the best stimulus of theoretical development, there are several theoretical issues that can be pursued before more empirical data accumulate.

5/ TEMAWS = Tactical Effectiveness of Mines in Armored Warfare Study--a series of tests at Fort Ord, California by the US Army Combat Developments Evaluations Command.

(3) Documentation of current combat representations (with and without obstacles) needs to be improved. Relevant changes in representations must be more quickly and widely distributed.

(4) Combat uncertainties must be given much more direct consideration. Several possible obstacle effects correspond to "localizations" with respect to time and location, in effect to changing some combat uncertainties. The analytic framework for considering this class of effects should include uncertainty (combatorics).

d. Among conceivable obstacles, FASCAM minefields seem to be receiving the most attention inside and outside the engineer community. Many of the largely unanswered questions that have already been surfaced during considerations of FASCAM are related to obstacle-free as well as other obstacle-related combat.

18. Prospects and Proposals.

a. Despite the evident difficulties, reservations, and risks, the obstacle-related combat problem is important enough to deserve highly visible, best-effort attention. Obstacle-related combat should be included on any list of the Army's most critical issues.

b. Given that there are so many surmountable weaknesses in both obstacle-free combat analysis (OFCA) and obstacle-related combat analysis (ORCA), we propose an almost salvo-like research approach to the problem without regard to a specific termination date. However, we do suggest several time, manpower, and working constraints. A broad-based approach

is proposed in the expectation that there will be successes in some areas that will lead first to sounder bases for specific, limited study and second to real advances in the state of the art, science, and understanding of obstacles. The goal is to reach the point where ORCA will have an appropriate, positive impact on doctrine and tactics, on hardware, on organization, on individual and unit training, and on dealing with our allies.

c. As general guidelines and constraints, we suggest the following:

(1) ORCA must not be approached as or become strictly an engineer activity. It must include multicommand, multiagency, multibranch participation.

(2) Both empirical and theoretical effort must be applied.

(3) ORCA must not become principally another model development process.

(4) An "exhaustive" list of conceivable obstacle-related battlefield events must be constructed (detailed to what individuals and individual crews may or may not do).

(5) In addition to the usual daylight, clear sky, open-ground scenarios, we propose at least equal effort be devoted to at least four obstacle-related, multitheme topics:

(a) Obstacles at night.

(b) Obstacles and smoke versus smoke.

(c) Obstacles and built-up areas.

(d) Obstacles and stalled/stopped engines.

(6) There must be a continuing TEMAWS-like program of trials. As a supplement to and motivator for trials, we favor direct analyst observation/participation in freer, training-like exercises.

(7) We favor the preparation of an "obstacle-related combat novelette." J. F. C. Fuller's early work on armor is sometimes described as a novelette. Hence, precedent, tradition, and prospect of greater impact favor this medium. Practically speaking, a well-written, easily-read concept paper is indeed often worth more than any or all conventional technical proofs.

(8) Our discussions with military and civilian analysts reveal the need for an "ORCA technical methods novelette." There is much good thinking going on about ORCA methods. However, because the thinking is incomplete, it remains largely undocumented. A paper or papers collecting technical method concepts should be prepared.

(9) Initially and admittedly somewhat arbitrarily, we favor devoting 80 to 90 percent of available ORCA effort to "tactical" matters (TAC-ORCA). In part TAC-ORCA should employ detailed representation of small-scale combat, in part applying the best of models/simulation/gaming. The 20 to 10 percent of remaining effort should be devoted to larger scale, quasi-strategic matters (STRAT-ORCA). In the spirit of combatorics, STRAT-ORCA should embark on far-ranging, mind-expanding

exploration and abstraction to integrate the "facts" from TAC-ORCA. The initial objective of STRAT-ORCA is to draw strategic conclusions from knowledge of tactical obstacles rather than to examine strategic barriers and obstacles as things in themselves. In contrast to TAC-ORCA, the STRAT-ORCA would be more theory- and less model-dependent.

(10) Because "combatorics" obviously departs from the Army's standard "expected value" approaches, we foresee a possible early and continuing need for the involvement (through consultant or contract) of some first-class mathematicians outside the regular Army-related study community.

d. The original ODCSOPS proposal is being considered in more detail in the light of this paper. The original proposal suggests that ESG (alone) will accomplish all objectives within one year, FY 77. ESG now considers that suggestion a bit unrealistic in scope, effort, and timing. ESG intends to prepare a mutually acceptable plan by October 1976 for FYs 77 and 78. In order to pursue the necessary variety of subproblems and approaches outlined in the foregoing discussion, the planned effort will almost certainly include other in-house and some contract participation. The total effort is to be phased in accord with the best estimates of empirical and theoretical problem needs and with the requirements of related Army decisions and studies. Certainly, some but not all known requirements can be satisfied within FY 77. Matched to in-process reviews (probably) at 6-month intervals, the plan will

provide decision points for the continuation, redirection, or termination of the separate parts of the total ORCA effort. ESG itself expects to have at most 4 TMY available during FY 77 for ORCA research, study, and coordination and no more than that for FY 78 work if required and authorized. One to 1 1/2 times the ESG level of effort probably will be planned for other in-house and contract participation.

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ANNEX A

SOURCES OF INFORMATION FOR THE MAIN PAPER

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1. The main paper is based on a variety of sources and experiences. Whereas no source was deliberately excluded, it cannot be guaranteed that all useful sources were known. A regular bibliography appears as Annex C.

2. Over the last few years, ESG's obstacle-related experience included the following.

a. Development of ADP system used in USAREUR barrier planning.

b. Contribution of section on the representation of obstacles and barriers in existing combat models to CAA paper, Barrier Utilization (U), CAA-TP-74-1, January 1974 (CONFIDENTIAL).

c. Publication of Terrain Evaluation for Antiarmor Weapons, March 1975 (UNCLASSIFIED).

d. Publication of Measuring Obstacle Effectiveness, A Fresh Perspective, March 1975 (UNCLASSIFIED).

e. Completion of soon-to-be-published Future Requirements for Nuclear Cratering Devices (U). (SECRET-RESTRICTED DATA).

3. Actions undertaken while appraising the state-of-the-art in measuring obstacle effectiveness include the following.

a. Rereading and reviewing.

(1) Accounts of selected campaigns and battles, including descriptions of actions around obstacles, as portrayed in derivative documents and reports.

(2) Several papers on the history of "movement rate data."

(3) Some combat model documentation. Justice may not have been done to current models. There are so many of them, and their documentation is so uneven that this side of the appraisal may have missed something outstanding.

b. Reconsidering some of the logical bases of combat modeling.

c. Attending the Antiarmor Systems Program Review, Ft Leavenworth, April 1976.

d. Attending the OACSI Threat Seminar, Aberdeen Proving Ground, June 1976.

e. Discussing the matter with an assortment of knowedgeable people--including the staff of the US Army Engineer School, Command and General Staff College, US Army Training and Doctrine Command Systems Analysis Activity (TRASANA), and Office, Deputy Under Secretary of the Army (Operations Research) (ODUSA(OR)).

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ANNEX B

REFERENCES TO AND COMMENTS ABOUT MOVEMENT RATE DATA

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REFERENCES TO AND COMMENTS ABOUT MOVEMENT RATE DATA

All actual and potential developers and users of combat models and "historical movement data" should read the papers by Wainstein[1/] and Mader.[2/]

Whereas Parsons[3/] and Hulse[4/] need never have been the nearly sole sources of movement rate tables, their infantry and armor studies appear to have been the Adam and Eve from which remarkably much has descended.

Parsons and Hulse were appropriately humble in their 1954 papers. They caveated their sources, conclusions, and the suggested range of applications of their results. Certainly, they would have been justified in even more caveats. But certainly too, more of their caveats would have been ignored just as the real ones have been.

Parsons used the data he did, not because those data were necessarily representative, but simply because they were the only data then

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1/ DOD, Inst for Def Anal, An Examination of the Parsons and Hulse Papers on Rates of Advance. (UNCLASSIFIED).
DOD, Inst for Def Anal, Rates of Advance in Infantry Division Attacks in the Normandy-Northern France and Siegfried Line Campaigns. (UNCLASSIFIED).

2/ DA, HQ, Models Review Com, Review of Selected Army Models. (UNCLASSIFIED).

3/ DA, Ofc, Chief of Army Field Forces, Combat Op Rsch Gp, Military Unit Rates of Advance in Attack. (UNCLASSIFIED).

4/ DA, Ofc, Chief of Army Field Forces, Combat Op Rsch Gp, Movement. (UNCLASSIFIED).

conveniently available. Since then, more data have become available. Most later "analysts," however, found it easier to borrow and modify the Parsons and Hulse data than to go to both old and newer sources.

Parsons and Hulse sought information about battalion-size attacks. They worked with relatively few attacks. But not all those few attacks were battalion size. They, nevertheless, clearly labeled their results as intended for use in battalion-attack analyses. Later analysts have often disregarded unit and force size and attributed size-independent significance to the results.

Parsons and Hulse wrote freely about ranges of advance rates even though not all their printed tables retained ranges of rates. Some later borrowers have collapsed the ranges into single values--with the almost certainly unjustifiable suggestion that the single values are means.

All the source data have one striking feature in common--their variability. In all cases, the variability is so large and the number of cases so small that the variance of the mean estimate must remain large. Even if we knew the true means, those means would be less characteristic measures of advance than are the variances. In other words, the variances are probably much more relevant to combat analysis than are the means.

Once variance is introduced, the propagation of variance must be considered. In particular, the analyst must come to grips with the extent to which aggregated quantities are correlated (or independent). In other words, analysts should begin with much more information about the covariances of quantities. If they do not have covariance data, at least they should much more clearly formalize their manifold assumptions about covariance. A point that is often missed is that analysts can make very powerful assumptions about covariances without knowing what covariance is. They do it all the time. The problem cannot be erased by refusing to learn definitions.

Some movement rates are expressed "per day"; some others are expressed "per hour." The transformations back and forth between "per day" and "per hour" seem to have been extremely casual. Whether casual or not, the transformations remain almost entirely undocumented. Without any obvious doubts, many data are applied as though given values are all actually expected values and all aggregations combine independent quantities.

Much of this behavior and its implications are hard to reconcile. "Winning the first battle" is alleged to exert very strong influences on the second battle. Is it not reasonable to suppose that the first moment of any battle is subject to some considerable uncertainty? Is it not also reasonable to suppose that the outcome of the first moment has some influence on the outcome of the second moment? Might we not expect that the distribution of gains in a second time interval depends

on the gains in the first time interval? We are suggesting some important dependence over time.

A typical attack consists of several attacking entities spread over some frontage. In any short time interval, we expect some differences in results among the attacking entities; some will do better than others. There is some mysterious mechanism that deals with combining the results of the attacking entities and that should govern the overall attack results in that short time interval. The attacking entities, then, are subject to some spatial distribution. To what extent are entities at different locations correlated at the same and different times?

Parsons and Hulse did not have accurate knowledge of attacker and defender strengths in all the cases they included in their analyses. Instead, they applied somewhat qualitative descriptors of "level of resistance." They also applied qualitative descriptors of terrain. Both Parsons and Hulse admit to injecting some judgment whenever data were less than complete. Several others have noted that some knowledge of attack success and movement rate is likely to influence a unit's and historians' judgments of resistance and terrain. Poor attack results are likely to bias judgment toward the conclusion that resistance was heavy and terrain poor. On the other hand, a successful attack

often leads to the conclusion that resistance was light and the terrain favorable. There are known cases in which such result-biased conclusions about resistance and terrain are incorrect.

Several authors note another seeming effect. Attack results tend to be influenced by what each side believes about the opponent and terrain. In addition to the exact level of resistance and quality of terrain, the expectation of heavy resistance and poor terrain tends to limit advance.

HERO[5/] suggests that perhaps the strongest influence on result is the stated objective. This, of course, is fairly obvious and subject to exceptions. We often offer a related comment about analysis and "measures of effectiveness." There is always something troubling about examining how well someone does something he did not regard as a primary objective or even care about. Yet, we often see analyses in which an action is seriously assessed for how well it compares with other actions in which objectives and concerns differed. This in itself is not misleading unless it is suggested (or only implied) that the actions all are truly comparable.

5/ DA, USCAA, Historical Evaluation of Barrier Effectiveness. (UNCLASSIFIED).

ANNEX C

BIBLIOGRAPHY

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BIBLIOGRAPHY

1. Department of Defense, Institute for Defense Analyses, An Examination of the Parsons and Hulse Papers on Rates of Advance. By Leonard Wainstein. Paper P-991. Arlington, Virginia, December 1973 (UNCLASSIFIED).

2. _____, Rates of Advance in Infantry Division Attacks in the Normandy-Northern France and Siegfried Line Campaigns. By Leonard Wainstein. Paper P-990. Arlington, Virginia, December 1973 (UNCLASSIFIED).

3. Department of Defense, Weapons Systems Evaluation Group, Preliminary Assessment of the Effectiveness of Weapon Systems Used by Opposing Forces in the October 1973 Middle East War (U). Arlington, Virginia, February 1974 (SECRET).

4. Department of the Army, Headquarters, Models Review Committee, Review of Selected Army Models. Washington, D. C., May 1971 (UNCLASSIFIED).

5. Department of the Army, Headquarters, Office of the Deputy Chief of Research, Development, and Acquisition, Improving the Army's Anti-tank Capability Study (U). Washington, D. C., May 1975 (SECRET).

6. Department of the Army, Office, Chief of Army Field Forces, Combat Operations Research Group, Staff Memorandum, Military Unit Rates of Advance in Attack. By LTC Norman W. Parsons. Fort Monroe, Virginia, 14 September 1954 (UNCLASSIFIED).

7. _____, Staff Memorandum, Movement. By COL Allen D. Hulse. Fort Monroe, Virginia, 9 August 1954 (UNCLASSIFIED).

8. Department of the Army, Office, Chief of Engineers, Engineer Studies Group, Future Requirements for Nuclear Cratering Devices (U). Draft. Washington, D. C., August 1976 (SECRET-RESTRICTED DATA).

9. _____, Interim Results--Fortification Obstacle Effects Simulation (FOES). Unpublished. Washington, D. C., June 1974 (UNCLASSIFIED).

10. _____, Measuring Obstacle Effectiveness--A Fresh Perspective. Volume I. Washington, D. C., March 1975 (UNCLASSIFIED).

11. Department of the Army, Office, Chief of Engineers, Engineer Studies Group, Terrain Evaluation for Anti-armor Weapons. Washington, D. C., March 1975 (UNCLASSIFIED).

12. Department of the Army, US Army Combined Arms Combat Developments Activity, Senior Attendee Fact Books--Antiarmor Systems Program Review ASPR): Trainor Report Fact Sheets, Presentation Abstracts, and Summary (U). Fort Leavenworth, Kansas, April 1976 (SECRET).

13. Department of the Army, US Army Command and General Staff College, The Feasibility of Measuring the Contribution of Artificial Obstacle Systems to Force Performance. Thesis by MAJ H. O. Boone. Fort Leavenworth, Kansas, 1975 (UNCLASSIFIED).

14. Department of the Army, US Army Concepts Analysis Agency, Barrier Utilization (U). Technical Paper CAA-TP-74-1. Bethesda, Maryland, January 1974 (CONFIDENTIAL).

15. _____, Historical Evaluation of Barrier Effectiveness. Contract No. DAA 639-74-C-0033. Dunn Loring, Virginia: Historical Evaluation and Research Organization, March 1974 (UNCLASSIFIED).

16. Department of the Army, US Army Engineer School, Family of Scatterable Mines Study, Phase III (U). Volume I. Fort Belvoir, Virginia, April 1974 (CONFIDENTIAL).

17. Department of the Army, US Army Training and Doctrine Command, Training Systems Analysis Activity, Memorandum to Combat Developments Experimentation Command, Outline Test Plan for TEMAWS. White Sands Missile Range, New Mexico, 11 May 1976 (UNCLASSIFIED).

18. _____, Report of the Research Study Group on Anti-armor Defense (U). By Dr. Wilbur S. Payne, Panel on the Defense Application of Operational Research. White Sands Missile Range, New Mexico, July 1973 (NATO-CONFIDENTIAL).

LAST PAGE OF ANNEX C